Oceanographic Measurement Surveys Using a Custom AUV: Mixing Induced in the Upper Mixed Layer on a Continental Shelf During Adverse Weather Conditions

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LONG-TERM GOALS

The principal long-term goals of this work are to (i) contribute to the development of physics-based numerical models for accurate assessment and prediction of the ocean environment, and (ii) develop state of the art system for oceanographic observations from one or more AUV surveyor platforms. Our contribution is based on developing accurate parameterization of the active small-scale processes in the water column through observations from fixed and mobile AUV platforms. The parameterizations are needed to correctly model subgrid scale processes in predictive numerical models. The aim is to develop the necessary data bank to help parameterize the sub-grid processes under various, measured background conditions.

OBJECTIVES

(i) Determine, using a custom AUV platform, the structure of the subsurface oceanic layer, including distribution of bubbles, currents, thermohaline fluxes, and rates of dissipation and mixing, together with the structure of the close-bottom boundary layer during high onshore wind events. The aim is to parameterize the physical processes induced in the subsurface layer and the bottom boundary layer by the atmospheric forcing for incorporation and validation of models of these processes.

(ii) Develop a custom, dedicated surveyor AUV, for making quality oceanographic measurements for use in the proposed and future oceanographic experiments under a variety of scenarios.

APPROACH

The following tasks were identified in pursuing the objectives:

Task 1 Development of a custom AUV Using previous experience with the Ocean Explorer as a basis, a custom vehicle will be developed taking account of the considerations such as vibration isolation of the AUV machinery from the payload section and chatter-free control. For greater versatility, it would be desirable to increase the depth rating from 300m to a 1000m, say. Such an increase will allow future missions in the Gulf Stream and will involve modification of the pressure hull. The robustness of the vehicle and its operation to stormy conditions will also be a requirement. We will work closely with the Bulefin AUV development team to ensure that the necessary requirements are met and details of

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14. ABSTRACT
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15. SUBJECT TERMS

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the navigational and positional accuracies are determined. The present Odyssey III will require some modification to accommodate custom sensor systems developed previously at FAU under this effort.

Task 2. Implementation of the oceanographic measurement sensors The sensor system on the custom AUV will include: a GPS navigation system, a compass, a motion sensor package, an upward (600kHz) and a downward-looking (300kHz) ADCPs, a Seabird FastCAT CTD package, a microstructure turbulence package, consisting of two shear probes, and fast response conductivity and temperature sensors, a broadband (6-196kHz) bubble resonator designed by David Farmer's group, two 300Hz sidescan and one vertical look sonars, and an ARGOS communication system. The possibility of implementation of a single custom upward and downward looking ADCP, of the type mounted on the REMUS vehicle, will be explored with RDI.

Task 3. Test of vehicle and sensor system operation. (Now scheduled for summer 2003). The mixed layer mission of July 1999 will be repeated as part of the test, extending the scope to include measurements afforded by the additional sensors and operation in high wind conditions. The object will be to make turbulence measurements and gain experience with making the bubble measurement with the new vehicle during high southeast wind conditions.

Task 4. Analysis of data acquired during fall 2000. Analyze bubble and turbulence distribution measurements carried out during previous year.

Task 5. A Fall Experiment in high onshore wind conditions A field experiment (now scheduled in fall 2003) involving an AUV survey of the upper mixed layer under high onshore wind conditions at the SFTF site is proposed.

WORK COMPLETED

Task 4 has been completed, and has resulted in a PhD thesis. Publications on wind driven flow are under preparation. Progress on other tasks has been delayed in view of the delay in receiving the incremental funding. The funding has now been received. Task 1: Bluefin's Odyssey III vehicle, with a depth rating of 3000m, has been selected as the AUV for proposed work Tasks 2, 3 and 5 will follow task 1. A limited experiment will be carried out with existing Ocean Explorer AUV during Winter 2002 using an existing AUV team at FAU. A no-cost extension will be requested to complete the work..

Analysis of measurements from a mixed layer mission in summer 1999 has been reported in special AOSN issue of IEEE Journal of Ocean Engineering.

RESULTS

Analysis of April 2000 field experiments have been completed and preparation of publications are underway. AUV surveys of the water column in littoral waters of the Southeast Florida coast were carried out, in conjunction with observations from fixed systems, during the passage of two consecutive atmospheric fronts in April 2000. Synoptic and in-situ observations included wind and wind stress (ASIS), air temperature, surface (OSCR) and subsurface currents (Bottom-mounted ADCP and AUV), CTD (AUV and ship-based casts) and small-scale turbulence (AUV). The observed subsurface structure is characteristic littoral zone response to atmospheric forcing associated with low-pressure cold atmospheric fronts that repeatedly descend and pass through the region. The near shore

water column in the region was subjected to three main forcing elements during the three survey experiments: 1) cold air outbreaks; 2) strong fetch-limited winds; and 3) the meandering Florida Current. The cold air outbreaks appeared to enhance the mixing and increase the dissipation rates, though their effects could not be completely isolated from the other contributing forcing functions. The fetch-limited winds produced strong shear in the water column and introduced subsurface currents consistent with wind-generated flow, in the absence of significant wave activity. At times, especially during the survey of April 8 and 9, 2000, the wind appeared to be the dominant contribution to the subsurface structure. Uniquely absent from the region during these events were the formation of strong internal waves and the surface mixing induced by significant surface waves. The rapidly changing subsurface structure suggests that the internal waves did not have time to develop. The density stratification in response to the cold air and solar heating underwent variations over 4 hour time periods.

The OEX AUV (Fig. 1a) provides a good platform for measuring subsurface currents, CTD and small-scale turbulence. The low vibration characteristics of the platform allow measurement of dissipation rates of $O(10^{-8})$ W/kg. The versatility of the AUV allows construction of horizontal and vertical maps of the physical variables. Specific conclusions relating to observed responses of the water column for each of the three separate atmospheric cold fronts studied here may be summarized as follows.

Cold Atmospheric Front of April 8-9, 2000: Accompanying this particular low-pressure atmospheric cold front over South Florida was a strong sustained northwest wind. A distinct change in current direction was seen with the change in wind direction as measured by both the fixed and the mobile ADCPs. The mean current profile and mean wind profile displayed a relation consistent with a wind generated current spiral, and showed a deflection of surface current direction of ~20° clockwise from the mean wind direction. The vertical water column was generally stable, though the column transitioned from stably stratified condition to uniformly mixed condition in a period of 3.5 hours. Significant contribution to the subsurface structure from the wind was observed during this experiment. The meandering Florida Current (FC) had markedly low influence on the survey region during this front, apparently its significantly further offshore location during the period. The consistent unidirectional winds and the clockwise-rotated current structure in the shallow water region suggests that wind stress was the major contributor to the subsurface structure. The CTD casts revealed mixing over the entire water column, the TS-plot featuring a classic collapse to a point during the passage of the front. There was good agreement between the local bottom-mounted ADCP and the AUV ADCP observations. Results of the observation are shown in Figures 2 and 3.

Cold Atmospheric Front of April 18-19, 2000: The low-pressure atmospheric cold front that passed through the South Florida region on April 18 and 19, 2000, greatly influenced the dynamic behavior and distribution of the physical properties in the water column. The atmospheric front represented a large system affecting the entire region from Lake Worth to Fowey Rocks, a distance of 110 km. The FC was markedly in-shore and appeared to bear significant influence. Density and temperature distributions in the water column varied greatly due to the combined influences of the cold air outbreak and the FC. The distinct influence of the surface cooling was, however, fairly distinct. The water column underwent a transition from being stably stratified to being uniformly mixed over a 4-hour period to being stably stratified again over a subsequent 4-hour period. Another aspect of the passage of the front was the presence of the shifting winds. The surface wind leads to a shear flow in the water column. The influence of the wind shear on the water column was much stronger at the beginning of the passage of the front and became reduced as time progressed. Dissipation rates were obtained for

both the horizontal plane surveys and vertical plane surveys carried out by the AUV. The measured dissipation rates appear to be in good agreement with the log law, at the start of the passage of the front, but deviate from it significantly as the front progressed. Horizontal distributions of dissipation appear to be lognormally distributed. The major factors influencing the vertical distribution of dissipation rate appear to be the wind shear, the bottom boundary layer, and the buoyancy flux. The water column was unstable for nearly the complete period of AUV operations. Additional research in decomposing the influencing factors on the region needs to be performed. Evidence of the Florida Current's influence on the littoral zone needs to be examined more closely. Additional survey experiments of atmospheric fronts in the winter months should be performed to better quantify the effects on the subsurface structure of stagnant fronts and to better understand the complicating factors such as the FC, surface waves, and diurnal heating. Results of the observation are shown in Figures 4-9.

IMPACT / APPLICATIONS

An AUV dedicated for oceanographic measurements will provide quality information about physical subsurface processes, over a range of scales, which underlie synoptic scale observations such as from a satellite or a surface current radar.

TRANSITIONS

Collaboration with University of Miami, University of Victoria, Canada, and Institute of Ocean Sciences, Canada are continuing. Proposals are being written to NSF, and NOAA for application of the dedicated AUV in longer term oceanographic experiments.

RELATED PROJECTS

The work is carried out in conjunction with N00014-00-1-0218 and other ONR-322OM/AOSN projects funded at Florida Atlantic University.

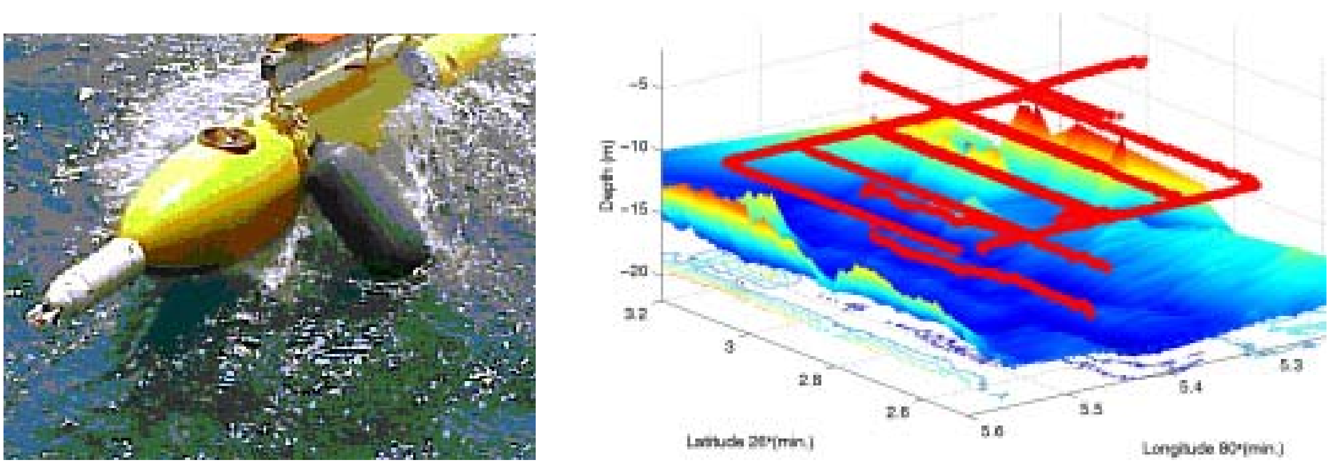

Figure 1 (a) OEX AUV and sensor systems, (b) AUV survey path

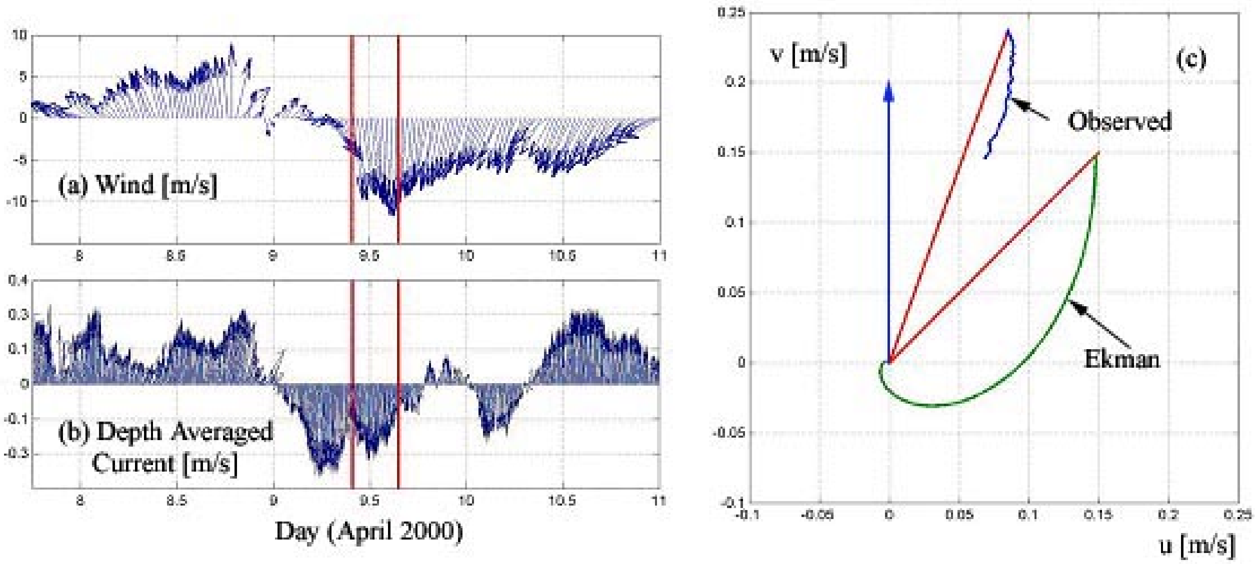

Figure 2 (a) Wind and (b) depth-averaged subsurface current vectors during April 7-11, 2000. The red-lines mark the period over which time averaged currents were considered. (c) Hodograph of time-averaged subsurface currents, compared with Ekman solution for deep water. The blue arrow indicates relative wind direction.

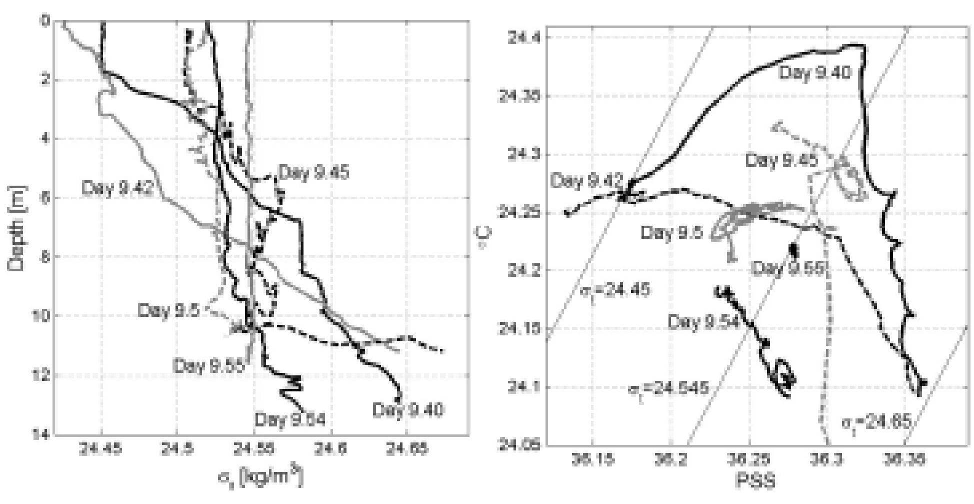

Figure 3. (a) Variability of density distribution during the passage of the cold front on April 8-9, 2000, and (b) associated T-S plot showing the point collapse of the variability

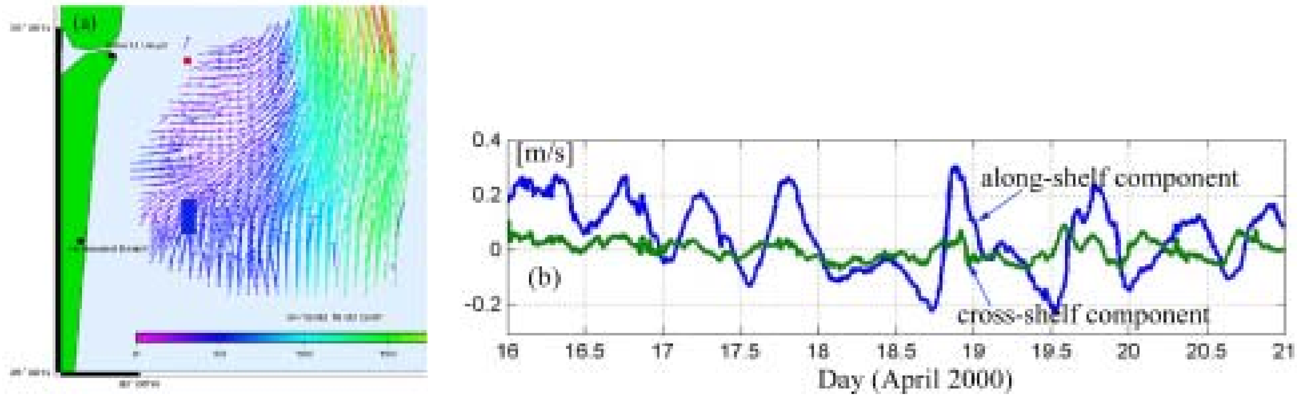

Figure 4. (a) Surface currents at April 2000 day 18.8, (b) Time series for depth-averaged subsurface current measured by bottom-mounted ADCP at location marked by the red square in map (a).

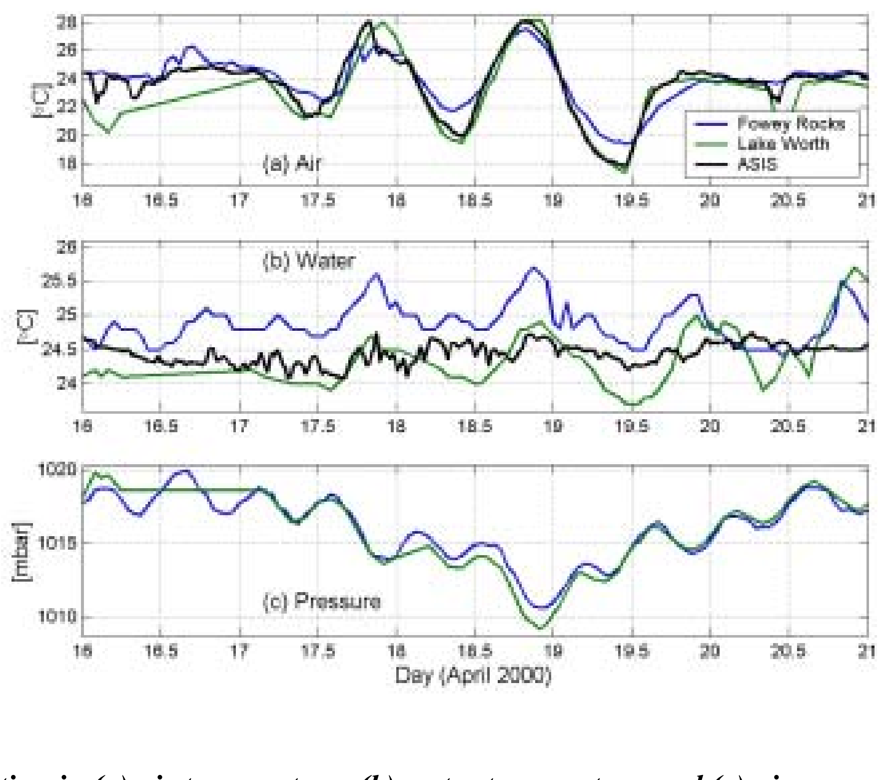

Figure 5. Variation in (a) air temperature, (b) water temperature and (c) air pressure in response to the passage of the atmospheric front at three locations along the South Florida coast.

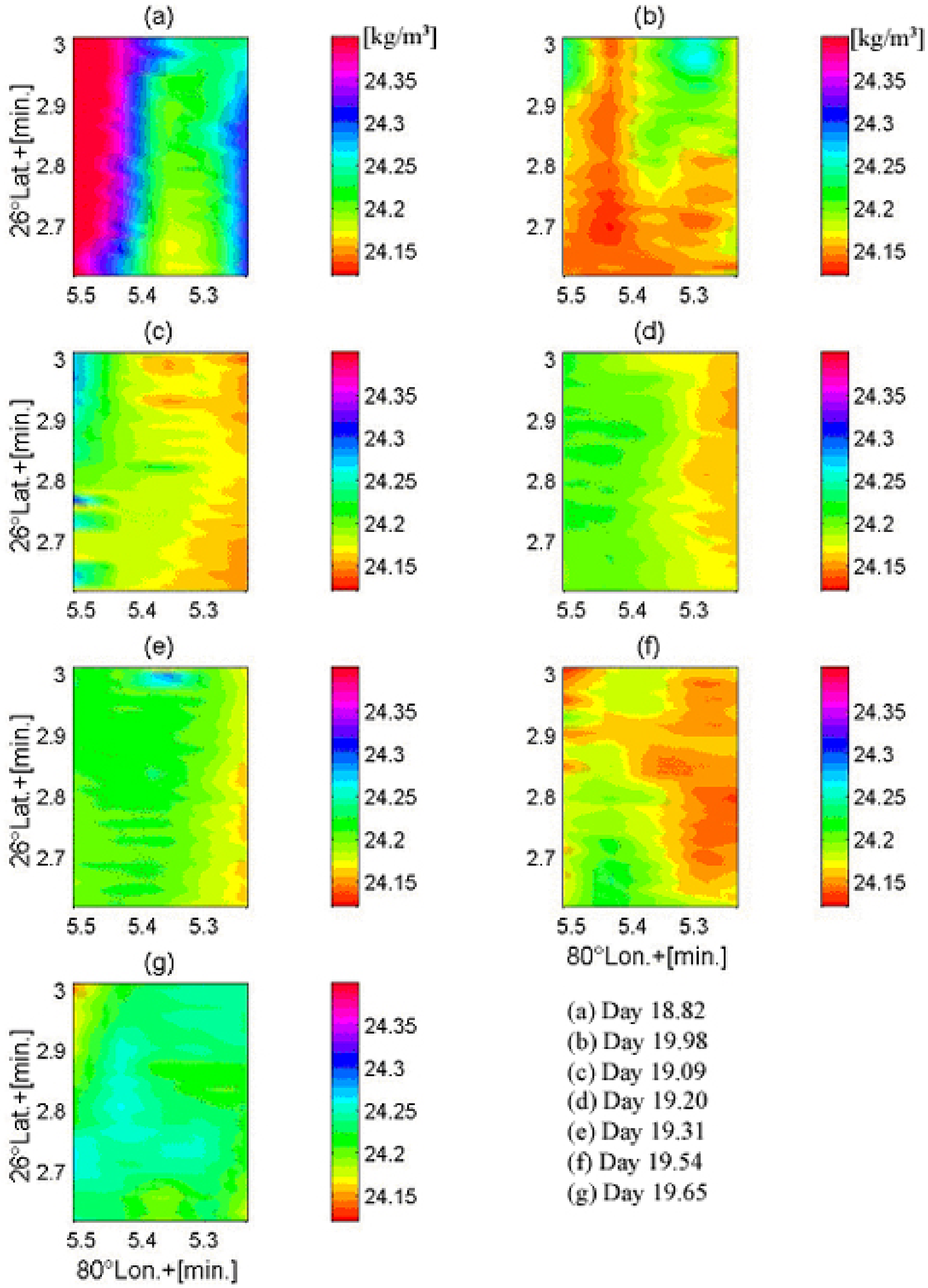

Figure 6 Variation in distribution of density at 10m depth in response to the passage of the atmospheric front as inferred from in-situ observation from the AUV

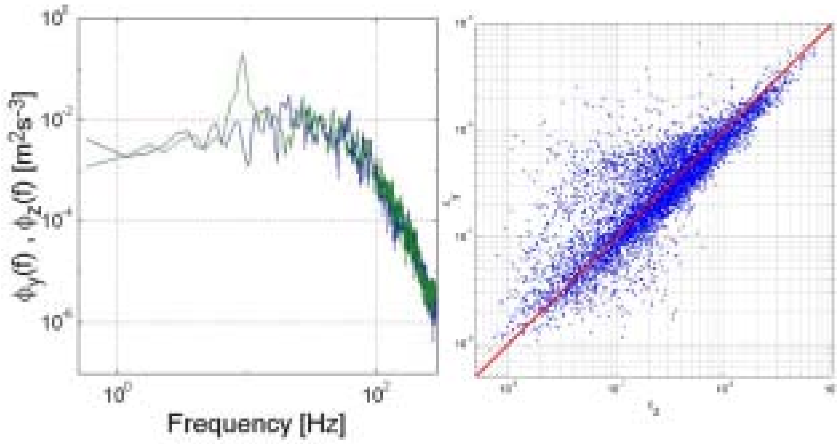

***Figure 7. (a) Dissipation spectra from y and z cross-flow shear probes mounted on the AUV, (b) Comparison between** ε_y and ε_z*

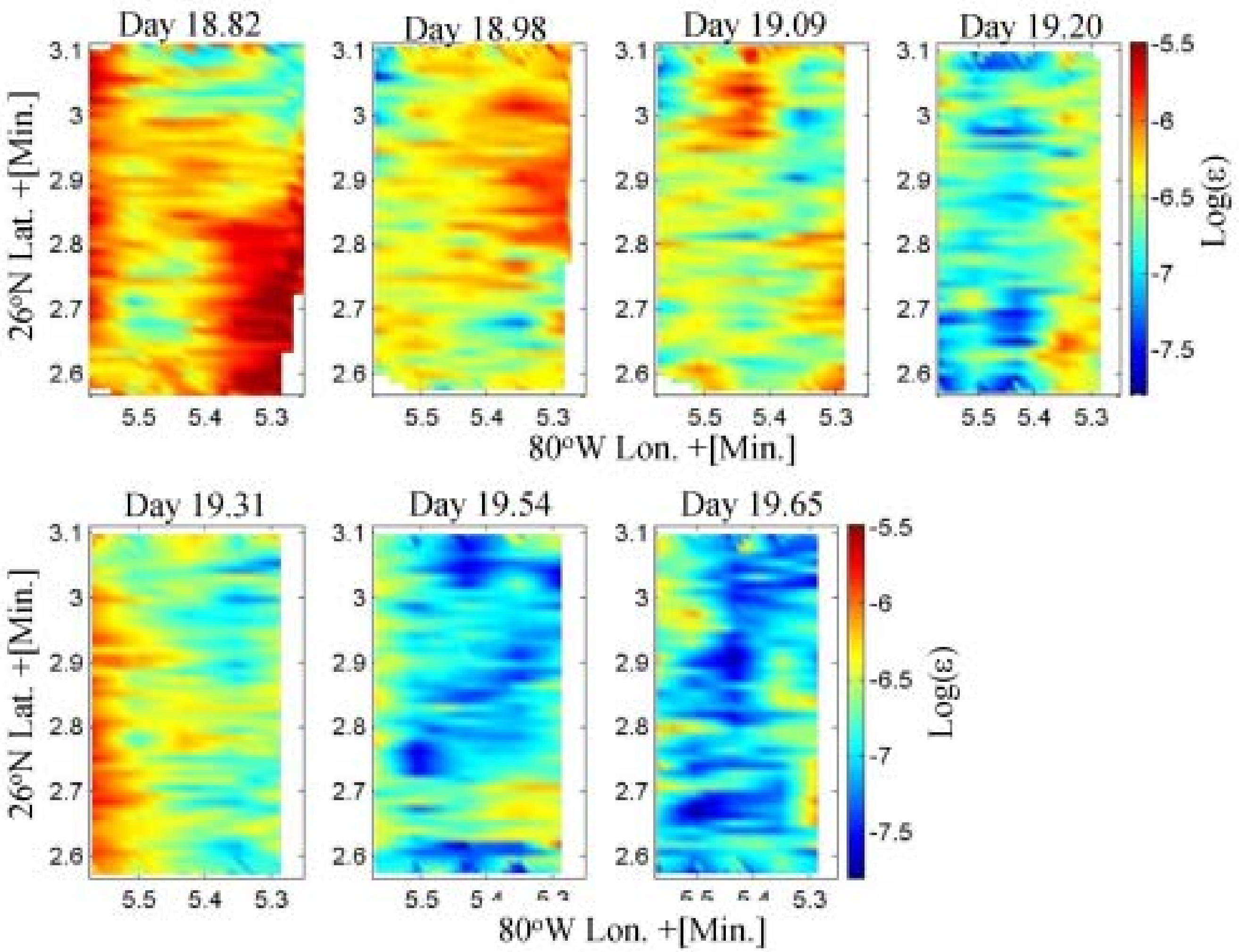

Figure 8 Variation in distribution of rate of kinetic energy dissipation at 10m depth corresponding to the density variation shown in Figure 6.

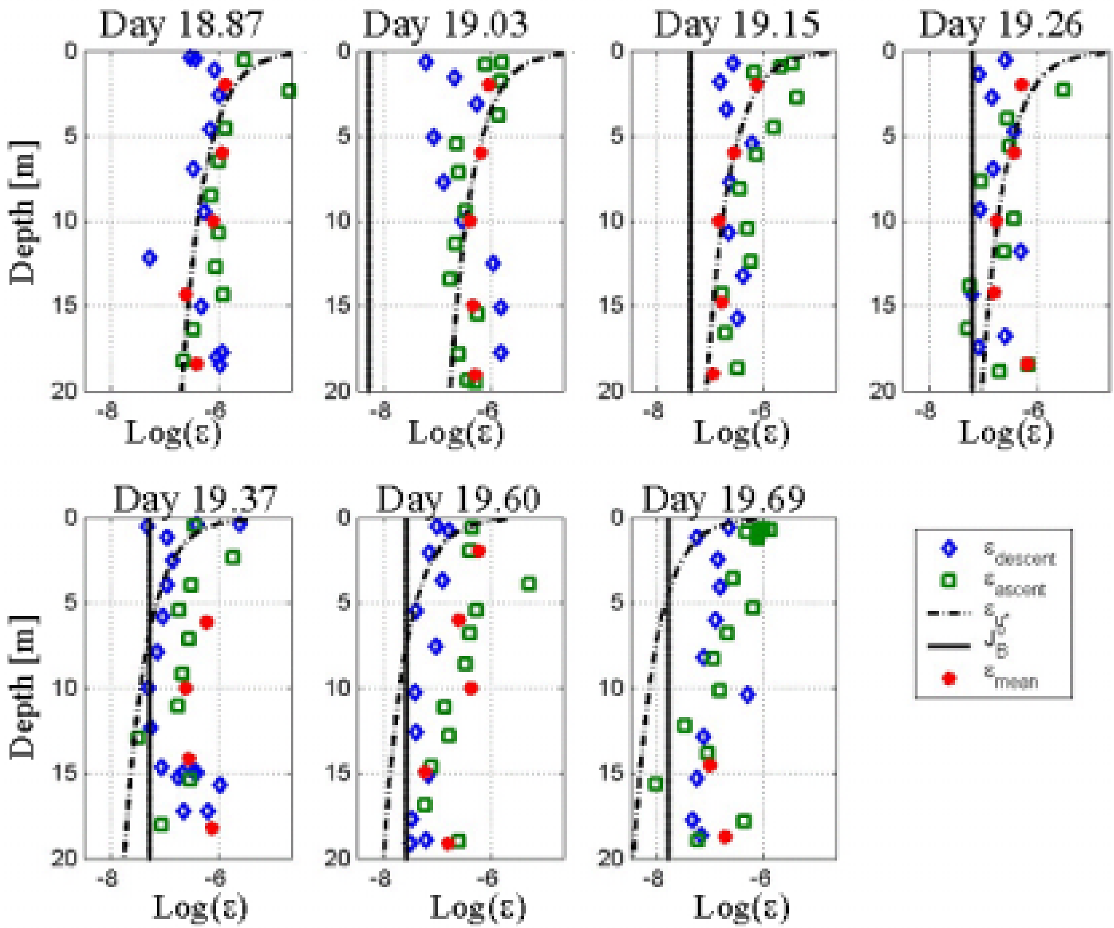

Figure 9. Variation in vertical distribution of rate of dissipation of kinetic energy observed during decent and ascent of the AUV during the passage of the atmospheric front

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PUBLICATIONS (Fall 2001 - Summer 2002)

1. *An AUV Survey in the Littoral Zone: Small-scale Subsurface Variability Accompanying Synoptic Observations of Surface Currents*. Manhar R Dhanak, Edgar An, and Ken Holappa. 2001. IEEE Journal of Oceanic Engineering. 26, 752-768.

2. *Subsurface Structure of an Atmospherically Forced Water Column in Littoral Waters,* M. Chernys, Ph.D. Dissertation, Florida Atlantic University, 2002.

3. *On the Instability of Cross-Shelf Shear Layer at the Edge of the Florida Current*. M R Dhanak. American Physical Society Meeting. San Diego, CA, November 2001.

4. *Wind Induced Ocean Currents in Littoral Waters*. M Chernys and M R Dhanak. American Physical Society Meeting. San Diego, CA, November 2001.

5. *Integrated Observations From Fixed and AUV Platforms in the Littoral Zone at the SFOMC Coastal Ocean Observatory,* M R Dhanak. EOS Transactions Volume 82 No. 47 Abstract OS31D-05. American Geophysical Union Meeting. San Francisco, December 2001.

6. *Subsurface Observations in a Wind-Driven Flow in Littoral Waters off the East Coast of Florida* M. Chernys and M. Dhanak, EOS Transactions Volume 82 No. 47, Abstract for Poster, American Geophysical Union Fall Meeting, San Francisco, December 2001

7. *Subsurface Structure of an Atmospherically Forced Water Column in Littoral Waters - AUV-based Survey*, M. Chernys. Invited Lecture, Physical Oceanography Dissertation Symposium I Breckenridge, Colorado, 2002.